ELECTRON RADIOGRAPHY

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ELECTRON RADIOGRAPHY

The present invention generally relates to radiographic imaging systems, and, more specifically, to the use of electrons to produce radiographic images. This invention was made with Government support under Contract No. W-7405-ENG-36 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

BACKGROUND OF THE INVENTION

The imaging of objects is important in many current endeavors, including medical, pharmaceutical, and industrial investigations. Radiography, in general, is the process of producing images of opaque items by the penetration of radiation, such as gamma rays, x-rays, or charged particles, such as protons, electrons or muons. When a beam of such radiation is transmitted through a heterogeneous item, the radiation is differentially affected by its varying thickness, density and chemical composition. The radiation emerging from the items forms a radiographic image, which is formed on an image detection medium, such as onto a photographic film directly, or onto a phosphor to convert the radiation to visible light, which is then imaged.

As seen, radiography is a non-destructive method of imaging the internal features of objects. It often is used to non-destructively detect medical condition such as tuberculosis and bone fractures, and in manufacturing processes to detect defects such as voids, cracks, and porosities.

The use of high-energy protons to produce these radiographic images is a mature technology for many imaging applications. However, this type of proton radiography has several drawbacks. Among these are the reasonably low resolution of small density differences, a lack of ability to image thin objects, and the creation of a relatively high level of residual radiation in the imaged object.

The present invention solves these problems with conventional radiography by providing apparatus for the non-destructive imaging of objects

using electrons as the charged particles. The electrons provide superior resolution and sensitivity in the imaging of thin objects.

SUMMARY OF THE INVENTION

In order to achieve the objects and purposes of the present invention, and in accordance with its objectives, an apparatus for performing electron radiography of an object comprises a source of electrons, with diffuser means receiving the electrons for diffusing said electrons. First matching quadrupoles receive the diffused electrons for focusing the diffused electrons prior to the diffused electrons entering the object placed in the path of the diffused electrons. First imaging quadrupoles receive the focused diffused electrons after the focused diffused electrons have been scattered by the object for focusing the scattered electrons. First collimator means receive the scattered electrons for removing electrons that have scattered to large angles, and second imaging quadrupoles receive the collimated scattered electrons for refocusing the collimated scattered electrons and mapping the focused collimated scattered electrons to transverse locations on an image plane representative of the electrons' positions in the object.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and form a part of the specification, illustrate an embodiment of the present invention and, together with the description, serve to explain the principles of the invention. In the drawings:

FIGURE 1 is a schematic drawing of an embodiment of the present invention illustrating the components involved.

FIGURES 2A and 2B are illustrations of electron trajectories through the embodiment of the invention shown in Figure 1 for the ideal electron trajectories and for the electron trajectories when scattered by passing through an object inserted into their paths, respectively.

FIGURES 3A and 3B are radiographs produced by use of the present invention.

FIGURES 4A and 4B are a radiograph produced by the use of the present invention of an aluminum step wedge, and a graph of transmission versus position for steps having a width of 1 cm and steps of 0.002, 0.004 and 0.006 inches, representing areal densities of 14-42 mg/cm^2.

DETAILED DESCRIPTION

The present invention provides radiograph imaging utilizing high-energy electrons, allowing the invention to image extremely thin objects. The invention can be understood most easily through reference to the drawings.

Referring first to Figure **1**, where a schematic illustration of electron radiography system **10** of the present invention is shown. A beam of electrons **11** from a source of electrons enters collimator **12** and passes to foil diffuser **13** where the beam is spread out as it progresses to matching quadrupoles **14**. Matching quadrupoles **14** modify the path of beam of electrons **11** to focus the electrons prior to entering vacuum chamber **15**, in which object **16** resides. Matching quadrupoles **14** operate to set up the proper characteristic for beam of electrons **11** for injection into object **16**.

As beam of electrons **11** pass through object **16**, their trajectories are scattered by Coulomb interactions with electrons in object **16**. After exiting object **16**, beam of electrons **11** is focused initially by imaging quadrupoles **17**. Beam of electrons **11** that have been scattered to a great extent are then removed by collimator **18** in vacuum chamber **19**. The remaining electrons in beam of electrons **11** then pass through imaging quadrupoles **20**, where they are focused before creating an image at image location **21**. Imaging quadrupoles serve to re-form the image of object **16** after contrast has been introduced by collimator **18**.

The quantity of electrons of beam of electrons **11** not removed by collimator **18** at each position in the image provides information on the thickness of object **16** at that position. Thin sections of object **16** scatter fewer electrons

into collimator **18** than thick sections of object **16**. Therefore, the transmission fraction of electrons in beam of electrons **11** that pass completely through electron radiography system provide areal density information about object **16**.

Beam of electrons **11** utilizes 20 MeV electrons that are very interactive. This greatly contributes to the ability of the present invention to detect very small variation in areal density of thin objects **16**. Such electrons are readily available from medical electron and other sources.

Figure 2 illustrates the path of beam of electrons **11** as it passes through electron radiography system **10**. At Figure 2A, beam of electrons travel along their ideal trajectories because there is no object **16** to scatter the electrons. In Figure 2B, an object **16** has been inserted into electron radiography system **10**, causing the electrons to be scattered as they pass through object **16**. Figure 2B shows how electrons that are scattered to large angles are removed by collimator **18**, and how electrons that pass through collimator **18** are re-formed to an image at image location **21**.

Those having skill in this art will readily appreciate that imaging quadrupoles **17**, **20** function to establish a one-to-one position map of electron beam **11** from its being scattered by object **16,** to image location **21**, thereby forming the image of object **16**. At collimator **18**, the radial position of electrons in electron beam **11** is proportional to the scattering angle imposed on the trajectory of electrons while traversing through object **16**. Collimator **18** being located between imaging quadrupoles **17**, **20,** selectively removes the electrons that are scattered to large angles. This greatly contributes the image contrast achieved by the present invention.

As an example of the efficacy of the present invention, a 1/16th inch thick Aluminum plate had the letters "LANL" machined through it. This plate was inserted into electron radiography system **10**. The resulting radiograph is shown as a digital image in Figure 3A. The resolution of this image is approximately 300 μm, as expected from prior predictions of the resolution.

In another test of the sensitivity of the present invention to accurately image thin systems, a "GOLD MARKER" PILOT® pen was used to write the letters "eRad" on a piece of paper. The ink in this pen contained 17% copper by weight, and resulted in a deposition of a <0.001 inch layer of copper on the paper. As seen in the digital image in Figure 3B, the letters are completely readable.

To determine the usefulness of the present invention in imaging step type changes in objects, an aluminum step wedge was imaged. This particular step wedge had steps that were 1 cm wide and 0.002, 0.004, and 0.006 inch thick. The step wedge represents areal densities of 14-42 mg/cm^3. The radiograph is illustrated as a digital image in Figure 4A, and clearly shows the individual steps of the step wedge. A plot of electron transmission versus position is illustrated in Figure 4B for the radiograph of Figure 4A. This plot graphically portrays the ability of the present invention to accurately image small differences in the density of an object.

All of these tests were conducted with 20 MeV electrons. As previously stated, such electrons are readily available from readily available sources, which are much more easily constructed than are proton sources.

Those skilled in this art also will appreciate that magnification could be introduced into the present invention to further improve its already excellent resolution. The optics of the present invention would be similar, but magnification would set up a 1-to-M mapping, where M is the magnification factor.

The foregoing description of the invention has been presented for purposes of illustration and description and is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the

art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.